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Art. XII.—*Notes on the Geology of Broadmeadows.*

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(With Plates XLIII.-XLIV.)

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Introduction.

The area dealt with in this paper has been mapped by the Geological Survey of Victoria on the quarter sheet No. 2 S.W., and lies mainly in the parish of Will Will Rook, and the northern part of the parish of Tullamarine, in the County of Bourke. It includes the low granitic hill of Mt. Gellibrand and the valley of Broadmeadows.

The following stratigraphical horizons are met with:—

Post tertiary	-	Alluvium.
		Limestone.
Tertiary -	-	Newer basalt.
		Sands and quartzites.
		Older basalt.
		Clay bed.
Palaeozoic	-	Devonian.
		Silurian.

These will be considered in order, commencing with the oldest.

Physiography.

The area is drained by the Moonee Ponds Creek and tributaries, whose valley is separated by a basalt-capped ridge from the valley of the Saltwater River, two or three miles to the west. This ridge continues northwards and southwards, and the two valleys remain more or less parallel throughout their whole length till finally, still distinct, they enter the Yarra.

The township of Broadmeadows lies sheltered in the valley of the Moonee Ponds Creek, immediately above the confluence of the right and left branches. Below the township, the valley is walled on both sides by newer basaltic plains, where, with a depth of 150 feet and an average width of 25 chains, the sides have an average slope of 1 in 4. Here, then, the valley is geologically young, and similar to all others which have been carved out on basalt plains. The youthful character is emphasised by the steep grade of the tributary creeks. The small tributary in Section VI., Will Will Rook, with a length of little more than half a mile, has an average slope of 1 in 20.

Above the township, where the two stream courses mark the junction of the newer basalt and the palaeozoic sediments, the valley presents a little more mature appearance. Lateral erosion has proceeded at a more rapid rate in the sediments unprotected by a basalt cap.

The present valley of Broadmeadows is post newer basaltic. The basalt streams, which probably came from the north (1) flowed round the granite hill called Gellibrand's Hill, and probably never covered the whole of the area now mapped as silurian. In the development of the new drainage system consequent on the lava flows, the streams, here as elsewhere, have found their easiest course along the junction of the basalt with the older rocks. So we find the upper part of the stream courses practically outlining the boundaries of the newer basalt with the granite, with the older basalt and with the silurian rocks. Of these the silurian sediments are least resistant to denuding agencies, and hence, while we find the granitic hill still maintaining its relatively high altitude, the old silurian hill, which banked up against the granite, has been very largely worn away and now forms part of the hollow in which the town of Broadmeadows is situated. The thin skin of basalt which consolidated on the lower southern slopes of this old hill is also partly worn away, as is evidenced by the presence of a small oval-shape outlier of newer basalt within the fork of the two branches of the Moonee Ponds Creek. This suggests that the course of the creek onwards towards the south has been determined by a southern continuation of this old silurian ridge from Gellibrand's Hill.

Silurian.

This sedimentary series is here, as throughout the Melbourne district, the fundamental rock. It is found well exposed in the stream valleys and beds, and is represented on the map as covering a fairly large area. This area is mainly well-grassed country, but exposures here and there indicate its extent. It is bounded on the north by the granite, on the north-west by the older basalt, and elsewhere by tertiary deposits. Lithologically they consist of a series of sandstones and mudstones, and a few shales with a strike about 42 deg. E. of N. Observations of the dips lead to the statement that most of the area is part of two dissected anticlines whose axes are represented by the dotted line on the map. On the quarter sheet these rocks are noted as "yellow and white argillaceous sandstones, with mottled red, yellow and brown ferruginous beds and olive-coloured shales." It is also stated that "in places along the Broadmeadows Creek 8 to 10 feet of drift composed of angular fragments of granite, trap and silurian, rests on the above and passes upwards into the soil; slightly sandy nodules like orthoceratites and gasteropoda are found on both sides of the creek in the shales."

With regard to the precise age of these rocks there is no direct evidence, as no fossils were found in this area. Silurian fossils are recorded from Keilor, five miles to the S.W., and as the lithological characters and strikes approximately agree, we can assign a silurian age to the Broadmeadows series.

Distribution and General Characters of the Granite.

The granite hill of Gellibrand forms a prominent feature of the area. Being partially wooded, it stands out in contrast with the treeless basalt plains and the cultivated and well-grassed silurian country. Though only about 500 feet high, an extensive view may be had from the summit in several directions. To the south stretches out the city of Melbourne and the shores of Port Phillip. To the north-east lie the Plenty Ranges, and to the north, closer at hand, are low volcanic hills and other granite hills. To the north-west lies the distant mass of Mt. Macedon, with the outstanding plug of solosbergite, known as the Camel's Hump. More to the west lies Mt. Blackwood, and the Werribee Gorge may also be seen. To the south-west rises Mt. Cotterill amongst other volcanic cones, and further on the bold outstanding granite peaks of the You Yangs.

The granite hill is part of a more or less circular outcrop of granite which has been cut in two by a north and south lava stream, and is the nearest outcrop of a granite massif to Melbourne, apart from granitic dykes in Melbourne itself. This was no doubt one of the factors bearing on its use as a building stone for the old Princes Bridge, Chief Secretary's Office, and Town Hall.

As to its geological relations, along the southern margin it is represented on the map as being in contact with the silurian, but the exposures are very poor. In a small creek in Section VIII. Will Will Rook, which runs down from the granite hill, the silurian sandstone and granite can be found *in situ* within a short distance of one another. The sandstone preserves the general strike, and shows no alteration, but on examination is found to contain pockets of shale. In Section IX., in the first exposure of silurian rocks met with in following down the bed of the creek, the general strike is not so well preserved. The shale bands here show evidence of squeezing, and contain nodular concretions of harder rock. One of these nodules was sectioned. From another shale band which appeared to be very indurated another specimen was taken and sectioned. Both these sections approached the hornfels type. A specimen was also obtained from a loose boulder along the approximate boundary in Section VII. This, when sectioned, was also found to be a hornfels.

The evidence (though small in quantity) is therefore distinct as to the slight metamorphism of the silurian sediments by the intrusion of the granite. The granite is therefore post silurian, and correlating with the Victorian grano-diorites, as we are justified in doing by its chemical and petrological characters, we may consider it as devonian in age.

Kaolinised Granite.

Along the creek in Section IX., Will Will Rook, is to be found a white face of kaolinised granite, exposed in a small gully about fifteen yards long. The outcrop, which does not reveal the extent of the material, is distinctly granite decomposed *in situ*, for there has been no resorting of the material. A rounded patch in the face contains much finer-grained material than the average, and represents a basic secretion in the original granite.

The material consists of unaltered, angular quartz with white mica set in white kaolin. The white mica and kaolin represent the secondary products of the original mica and felspar in the granite, while the quartz has remained unaltered. It is a question which cannot be decided on the available evidence, in what manner the change has been brought about. Such occurrences may be ascribed to subaerial agencies. Surface water and atmospheric carbon dioxide are capable of converting the alkalies present in the granite into carbonates which would be leached out, leaving a resultant product, chiefly kaolin and quartz. With regard to this it may be noted that the occurrence is very close to the contact of the basalt, and the conditions would be favourable to an excess of drainage along this junction. An alternative view is to regard the origin of the kaolin as due to pneumatolytic action of the emanations from the mass of cooling granite in its final stages of consolidation. This is the proved origin of kaolin deposits in Cornwall (2). The chief kaolinising agents in this case are shown by F. H. Butler (2) to be water and carbon dioxide. Fluorine and boron vapours often accompany them, and may result in tourmaline, fluorspar and topaz. Such minerals would most likely be concentrated along veins. No veins have been observed in the present case, and very little evidence is to be had for or against either theory. The pure white face and the abundance of white mica might lead one to lean towards the theory of a deep-seated origin.

Similar occurrence is found along the border of the granite outcrop at Bulla,[1] four or five miles to the north-west, and is the subject of a brief report by E. J. Dunn (3). The outcrop is of much greater extent, and the rock is spoken of as soft and crumbling, and consisting of ordinary quartz granules and kaolin, the latter replacing the felspars. He says it has been carted

1 Since writing the above, a discussion of the Bulla material has been published by Mr. R. W. Armitage, B. Sc. Vict. Nat., vol. xxviii., July, 1911.

at heavy expense to Northcote and to Ringwood, and used successfully for fire bricks and for lining furnaces. This outcrop, being nearer to Melbourne, may therefore be of value.

Associated Dykes.

In Section VIII., Will Will Rook, there occurs a line of boulders of quartz porphyry in the silurian country. The line is east and west, but is determined by a fence of a cultivated paddock. But it is evident that a quartz porphyry dyke occurs in the vicinity, which has shed these boulders in weathering. The rock consists of phenocrysts of quartz and felspar set in a very fine-grained ground-mass. The felspar has a rectangular outline, but is too decomposed to be retained in thin section. It is probable that this quartz porphyry dyke occurring so close to the contact of the silurian and granite is to be associated with the intrusion of the granite.

Chemical Characters.

A chemical analysis of this rock was carried out in April, 1909, at the Geological Laboratory of the Melbourne University, by Mr. H. S. Richards, M.Sc. The analysis has not been published hitherto, and it is Mr. Richards' generosity that makes it available now for discussion along with the petrographical characters.

The silica is lower, and the lime and magnesia higher than in a true granite. Still the total lime and magnesia is lower and the total alkalies higher than the Macedon grano-diorites. The total composition suggests that it is nearer to the adamellite type than the true grano-diorite. This suggestion is supported by the petrographical examination. The relative amounts of plagioclase and orthoclase were determined by a series of traverses across a rock slice, and it was found that the proportion of plagioclase to orthoclase was less than two to one. The position of the rock in the American system is—Class I., Persalane; Order 4, Brittanare; Rang 2, Toscanase; Sub-Rang 3, Toscanose.

Petrographical Character.

Megascopically the granite is a grey rock, coarse grained, and shows crystals of quartz, felspar and biotite.

Microscopically the crystallinity of the rock is seen to be holocrystalline, and non-porphyritic, with crystals of variable size. The average crystal size is medium, and the texture is hypidiomorphic. The minerals present are quartz, biotite, plagioclase, orthoclase, chlorite, muscovite, apatite, zircon, and magnetite. The quartz is allotriomorphic and contains inclusions of apatite and zircon.

The plagioclase is mostly idiomorphic. A zoned crystal without lamellar twinning has an extinction almost parallel to the trace of cleavage, thus indicating andesine. The zones become progressively more acid. The orthoclase is mostly untwinned and cloudy. The chief alteration product from the felspar is kaolin, but a little secondary white mica and calcite has also resulted.

Biotite is abundant in large and small ragged crystals, and contains inclusions of apatite, zircon and magnetite.

Green chlorite is abundant as a decomposition product of the biotite. Muscovite occurs in loose aggregates which appear to be secondary. Apatite is plentiful in small colourless crystals with low polarisation colours, which distinguish it from the less abundant, prismatic and pointed crystals of zircon with its high polarisation colours. The zircon also has a dark border.

Magnetite occurs in grains throughout.

The rock is not a true granite, differing from such in its content of andesine. It is not a true grano-diorite, since the plagioclase is not sufficiently predominant over orthoclase. It may be described as an adamellite bordering near a grano-diorite.

Sub Older Basaltic Rocks.

In section along the Moonee Ponds Creek below the older basalt quarry, a thin bed of about 2 feet is to be seen underlying the older basalt and resting unconformably on the silurian. It consists of a clay with much disseminated quartz grit, stained brown by iron solutions from the basalt. It is interesting in that it contains abundant material of what in the field appears undoubtedly fossil wood, but which on examination in the laboratory does not disclose cell structure. The cell structure may have been destroyed during the replacement of the organic material by limonite.

In the bed of the creek upstream from the quarry, decomposed older basalt may be seen above a clay containing quartz grit, which passes into a bed of more or less re-sorted kaolinised granitic material containing some white to brown mica. This in turn passes into a white clay. The observations are made in plan and are not too clear, and admit of two explanations. First that here, the only point in the district, we have an outcrop of a bed which may possibly be correlated with the lower tertiary leaf beds which underlie the older basalt at Royal Park (4) and elsewhere. Secondly, that the resorted granitic material is but a thickened part of the 2-foot bed observed lower down, which has not been so deeply ironstained, and that this in turn rests on a clay which is part of the silurian series.

Distribution and General Characters of the Older Basalt.

The older basalt occurs in an oblong-shaped area of undulating country to the west of Gellibrand Hill, and along the valley of the right branch of the Moonee Ponds Creek, in Sections VII., Will Will Rook, and XV. and XVI., Tullamarine.

The occurrence is the most northerly extension of the series which is found in Green Gully, Keilor, along the Saltwater at Sunshine, at Essendon, Moonee Ponds, Flemington and Royal Park. It is exposed on the hillsides and along the bed of the creek, but is best studied in some river cliff sections and in a quarry in the southern portion of the area. In this quarry the rock is perfectly fresh and shows a remarkably good columnar structure. The columns are best seen on the southern wall of the quarry, where they are well marked, though not so straight and clean cut as the newer basalt columns, known as the "Organ Pipes," near Sydenham; nor are they as high, being not more than 20 feet. On opposite walls of the quarry they are tilted in directions towards one another. On the N.W. face the columns are tilted at about 40 deg. to the vertical and at a much smaller angle on the opposite face. On the S.E. face the columns are in part vertical, and gradually pass into the inward sloping columns on both sides. The quarry therefore marks the site of a pre-older basaltic river valley. In a cliff section higher up the stream the columnar structure is again evident. Here in the upper part the columns are not so well defined, and in the lower part some of the columns are very small and more or less weathered. Still further up the stream the creek bed is formed of pavements or columns in plan. These are mostly hexagonal in outline, and frequently show irregular cracks, this being the first stage of their disintegration.

From the quarry a sample of the normal rock was taken, sectioned and analysed. From this fresh rock all stages in decomposition may be observed up to a soft, more or less iron-stained, wackenitic clay. In one section below the quarry the platy structure, and in part the spheroidal appearance, is developed, and at the bottom it is very soft and has the appearance of a red earth, which in the hand specimen has somewhat the appearance of a tuff.

As regards geological relations, its precise age cannot be determined in this area. It is clearly post silurian. Its relations with the tertiary quartzites will be discussed later. It occurs mostly at a lower level than the newer basalt, and though the two series come together in the northern part of the area, the two are not visible together in one section. Its chemical and petrographical characters show that it is distinct from the newer basalt, and that it may be correlated with the older basaltic series which has been shown to be in other parts barwonian (5).

Chemical Characters.

The analysis of this rock shows by the low percentage of SiO_2 its very basic character. The alkalies, totalling approximately 5 per cent., are greater than the average of the basalts for the SiO_2 percentage. This is impressed on one when working out the norm under the American system of classification, which brings an amount of nepheline into the composition of the rock. Its position in the classification is—Class III., Selfamine; Order 5, Portugare; Rang 3, Limburgase; Sub-Rang 4, Limburgose. The high percentage of combined water, 2.60 per cent., is notable, and finds expression in the large quantity of brown glass in the rock.

Petrographical Characters.

Specimen No. 24 was obtained from the older basalt quarry. Megascopically it is a very dark, hard and dense basalt which is rather brittle under the hammer. Crystals of olivine and a very occasional crystal of felspar can be observed in the hand specimen scattered throughout a dark-coloured matrix. The outer shell of the specimen contains no phenocrysts, and is distinctly more tachylitic. Microscopically the rock consists mainly of phenocrysts of olivine set with felspar laths and grains of augite in a ground mass of brown glass.

The olivine phenocrysts for the most part are clear and unaltered in imperfectly shaped crystals, though some good hexagonal and octagonal outlines may be seen. Some of these show simple and interpenetrative twinning. Stages in the alteration of the olivine to a yellow-brown mineral may be observed. This red-brown alteration product is more often seen than the intermediate stages, indicating that the change, once started, takes place very rapidly. This red-brown mineral corresponds with iddingsite, except that it is isotropic in the complete crystal. In the half-way stages it extinguishes in the same position as the olivine, and corresponds exactly with iddingsite.

The felspar is present in two distinct types. Most of the laths show lamellar twinning, and, in the measurement of the angle of extinction of the lamellae in a large number of sections, the maximum observed was 42 deg., while several values of 35 deg. were obtained. This felspar, then, according to the diagrams of Michel-Levy, is labradorite with the composition $Ab_3 An_7$. One large phenocryst of this felspar is present. It is corroded by the magma and is crowded by black inclusions. It shows but a trace of the lamellae, and also shows cleavage, and is therefore a section almost parallel to (010). Its extinction angle measured from the trace of cleavage is 41 deg., showing that in composition it approaches pure anorthite. In addition to this basic felspar there is a tabular felspar which has wavy extinction and is untwinned or simply twinned. In ordinary light it is mostly clear and colourless, and where cleavage is present it is found to have a very low angle of extinction. It is mostly allotriomorphic, but in places the crystal outline is partly discernible, and then it shows a tendency to a rhombic outline. Application of the Becke method shows that it has a refractive index lower than that of labradorite. The microscopical evidence is therefore in favour of its determination as a soda-orthoclase or anorthoclase, and this conclusion is in perfect concordance with the chemical analysis..

The augite occurs as small grains and prisms intimately associated with the brown glass. Its colour is yellowish-brown, indicating a titanium variety.

Apatite occurs as minute inclusions in the felspar laths, and grains of ilmenite or magnetite occur throughout. Microlites which are opaque, and therefore probably ilmenite or magnetite, occur abundantly throughout the brown glass. Microlites of felspar and augite may, in addition, be seen.

Besides the above minerals there is present a pale green mineral which is isotropic. It shows in part a banded appearance, and is some form of secondary amorphous silica, probably hyalite.

The rock may be described as an olivine anorthoclase (?) basalt.

Tertiary Sedimentaries.

These consist of fine sands, hard quartzites and coarse and fine ferruginous grits. Many of the boulders of quartzite contain rounded pebbles of quartz embedded in them. The ferruginous grits often contain nodular concretions of limonite. The quartzites and grits occur as a fringe along the sides of the valley underlying the newer basalt. The unconsolidated sands are well exposed in a gully in Section XV., Tullamarine, which drains into the Moonee Ponds Creek. Lower down this same gully the quartzites may be observed.

Pipe-like concretions of limonite, which look like branches of trees, have been observed in the grits, but these, like those at West Essendon (8), show on examination no trace of plant structure.

These sediments clearly underlie the newer basalt, and are therefore older.

Ascending the right branch of the Moonee Ponds Creek the first of the newer rocks to be found in contact with the silurian is, omitting the sub older basaltic clay previously discussed, the older basalt in a decomposed condition, showing platy structure and spheroidal weathering. Immediately following this is an outcrop of quartzites which appear to come down to the level of the silurian. Then 50 yards or so further on, the older basalt comes in again in the columnar quarry. In one place on the side of the valley the older basalt appears vertically above the quartzite. We must therefore consider two possibilities:—

(1). Quartzites, etc., older than the older basalt.

(2). Quartzites, etc., newer than the older basalt.

(1). That this was probably the conclusion of the officers of the Geological Survey is evident from the index on the quarter sheet. The quartzites, etc., are called "older pliocene," and the older basalt "pliocene" simply. R. A. F. Murray, in his Geology of Victoria (6), has referred to the existence of quartzites underlying the older basalt, but does not give examples.

This theory involves the likelihood that all the quartzites, grits and sands are not of the same age, for the unconsolidated sands occur at a much higher level than any part of the older basalt, and immediately underneath the newer basalt. It would enable us to read the section in the bed of the creek above the quarry with more confidence as a sub older basaltic tertiary bed, and therefore as a non-silicified part of the same series as the quartzites.

The evidence is chiefly the apparent vertical distribution of the older basalt above the quartzites.

(2). In this case the quartzites are read as resting on a differentially eroded surface of older basalt, and any apparent contradiction occurs where the quartzite is not *in situ* and has suffered hill slip. All the quartzites, grits and sands can then be taken as belonging to one series, or two conformable series. This view receives all the support of correlative evidence.

Lithologically this series is similar to the series of quartzites and grits and sands of West Essendon (10), which rests unconformably on the older basalt (10). Mr. R. W. Armitage records marine fossils, and assigns them to the kalimnan (miocene) period.

Even with the correlation, it is an undecided question whether these beds are marine or fluviatile, i.e., whether the kalimnan sea extended as far north as Broadmeadows, or whether these deposits were laid down in a river flowing through Broadmeadows into the kalimnan sea. Exposures of the iron-stained material which is found to be fossiliferous at Royal Park and West Essendon are so poor in this area that any thorough search for fossils is impossible. The negative evidence is therefore not of much value.

Newer Basalt.

The newer basalt is part of the eastern fringe of the extensive sheets of South-Western Victoria. Here it is part of flows which have come from the north, and possibly, according to T. S. Hart (1), from the low volcanic hills four or five miles to the north in the parish of Yuroke.

The newer basalt extends only as a thin capping which, as sections along the valley show, has flowed over almost level tertiary deposits. The surface of the flows is very scoriaceous, and the extent of this scoriaceous basalt indicates very little erosion since its consolidation. Still places are occasionally found where the basalt is in an advanced state of decomposition. This is usually assigned to ordinary processes of weathering which may have been localised in sundry ways. But it is more likely to have resulted from the chemical action, subsequent to consolidation, of enclosed magmatic waters and gases. That the magma contained large quantities of these is evidenced in the abundant material, chiefly arragonite, deposited on the walls of the vesicles.

Chemical Characters.

The rock analysed was collected from a point marked B on the map, and taken from the lower part of a small section along the river valley. According to the American classification the rock would be called:—Class I., Dosalene; Order 5, Germanare; Rang 3, Andase; Sub-Rang 4, Andose. The chief feature is the rather higher alkali percentage than that of the average of the 161 analyses of typical basalts collected by R. A. Daly (8). This finds expression in the petrographical description. The rather higher percentage of CO_2 does not mean that the rock is not fresh, but is explained by the presence of vesicles filled with arragonite.

Petrographical Characters.

Specimen No. 35 (B), Section VI., Will Will Rook. Megascopically it is a blue, even-grained rock in which crystals of green olivine, black augite, and felspar may be seen with the aid of a lens. A few vesicles may be seen lined with arragonite.

Microscopically it consists of phenocrysts of olivine, augite and felspar laths set in a ground-mass, partly felspar, partly augite, but mostly glassy.

The olivine crystals are often much altered in that along the edges and cracks the crystals have the appearance of iron staining. This iron-staining sometimes extends right across the olivine crystal, which then assumes the characters of iddingsite, dark-brown colour, slight pleochroism, and straight extinction.

The augite is developed in irregular plates or phenocrysts to a much less degree than olivine. It is occasionally twinned, and is of a very pale yellowish-green variety. The bulk of the augite is distributed as grains and prisms throughout the ground-mass. It is probably a titaniferous variety.

The felspar laths show lamellar twinning, and the measurement of the extinction angles of a large number of sections gives a maximum of 35 deg., indicating a labradorite of approximately the composition of Ab_2An_3. In addition there is another felspar with the same characters as the second type of felspar found in the older basalt, and therefore to be described as soda-orthoclase or anorthoclase.

Grains of magnetite or ilmenite occur scattered through the ground-mass, and minute prisms of apatite occur in the felspar laths.

The rock may be called an olivine anorthoclase (?) basalt.

Distribution and General Characters of Limestone.

The limestone occurs in a more or less irregular way along the valley of the left branch of the Moonee Ponds Creek. It occurs most extensively along a side gully and the bed of the tributary creek, from which it has been omitted from the quarter sheet. In places along the main stream—e.g., the point marked D on the map from which a specimen was collected and analysed, it may be observed to rest directly and unconformably on the folded silurians. It is not bedded, nor continuous, and is very variable in character. At the point marked C on the map, close to the boundary of the allotments X. and XIV., is a small excavation in the limestone rock from which a sample was taken and also analysed. Here it is a very hard, grey rock which weathers on the surface to a dull white, and which contains small disseminated quartz grains and scattered lumps and boulders of a scoriaceous and weathered basalt, such as is found on the surface of flows. At the locality D on the boundary of allotments IX. and XIV., it is of a white colour, much softer, and contains a great deal more quartz and other impurities. In addition to these two types there are many variations. It is found in every condition between the above and a black marl, when the percentage of admixed river silt is very large. In one section of creek alluvium it is found in the form of nodules in horizontal layers. This alluvial material is derived in part from the silurian rocks, in part from the basalt, and in part from the limestone, and therefore contains much magnesia. Rain water, on passing through, has partly dissolved out the lime and magnesia, and by means of the concretionary process has re-deposited the carbonates in more or less horizontal rows of lenticular concretions.

Fresh-water shells are to be found enclosed in the limestone in the bed of the creek, and more abundantly in the tributary creek. A specimen was very kindly examined by Dr. Pritchard, who stated it to be *Pomatopyrgus buccinoides*, Quoy and Gaimard, a species which may still be obtained living in the creeks in great numbers. Dr. Pritchard also tells me that some of limestone patches are made up very largely of *Coxiella confusa*, E. A. Smith. The late Professor McCoy originally referred to material from this locality as containing *Truncatellas*, but Dr. Pritchard has not seen any of this genus, and is inclined to think that perhaps *Coxiella* was the shell referred to by Professor McCoy.

Previous References.

The rock at C is described on the quarter sheet as a "cherty limestone too hard and impure to be profitably burnt for lime," and "of recent tertiary age," and, further, that it contains "brackish-water shells (*Truncatella filosa*) and living species." Reference is made to it by A. R. C. Selwyn (8) in his "Descriptive Catalogue of Rocks and Minerals," among the older pliocene rocks. He calls it an impure limestone which probably contains much magnesia, and was formerly burnt for lime. He states that it occurs underlying the newer basalt, with tertiary quartzites and ferruginous grits. He also notes that it contains fossil shells (*Truncatella*), and an analysis (quoted below by J. C. Newbery) is recorded. The same rock is again referred to by G. H. F. Ulrich, F.G.S. (9), under the heading, "Dolomite (Magnesian Limestone)," when the above statement of the occurrence is repeated, with the addition that in the bed of the creek, below the outcrop of the band, occurs a similar rock that encloses *Truncatella*, and is most likely derived from the former.

Geological Relations and Origin.

Along the small gully at C, the limestone, outcropping at a lower level than the newer basalt, does give the appearance of a bed underlying the newer basalt. The included boulders of basalt, however, clearly show that the bed must be younger than the newer basalt, and the outcrop can only be considered as a superficial plaster on the side of the gully extending but a few feet inwards, and not, therefore, to be associated with the tertiary quartzites and grits which do underlie the newer basalt.

All the evidence, variability of composition, lack of bedding and continuity, and the presence of lime-encrusted boulders, points to a chemical rather than a mechanical origin. This chemical origin may be ascribed to magmatic waters and rain waters which, percolating through the basalt, have dissolved out some of the lime and magnesia and re-deposited it along the prominent joint planes, and these have determined the direction of the streams. Hence we should expect the limestone to be found in greatest quantity along those directions which were joint planes, and this is actually the case. The limestone in the main creek, whose direction has not been determined by a joint plane, has accumulated partly by the main process and partly as a secondary product derived from material deposited in joint planes. G. H. F. Ulrich's statement, then, that the rock in the bed of the creek is, most likely, secondary, is probably correct in part. The original limestone in the big joint planes, while being washed by streams and rain, would be partly dissolved and re-deposited in other parts of the stream course, and in this way the shells of organisms living in the stream, many of the basalt boulders, and quartz and felspar grains have become buried in it. The rock thus formed is of the same age as the river alluvium. It is probable that the hard, compact, grey rock, which may be observed to weather to a dull white rock, is the original limestone, and the whitish rock along the main creek is mostly a secondary deposit of the same age as the alluvium, and derived from the former either by weathering or by solution and re-deposition.

That the limestone has been deposited from solution, and, further, that the process is still going on, is evident from the fact that many of the stones in the creek have incrustations of lime, and that there are boulders of fresh basalt, up to three and four feet in diameter, partially cemented into the rock. We also find this, where the main stream flows directly over the silurian bedrock, filling up cracks and joint planes in a manner which could only result from deposition from solution.

Correlation with Similar Victorian Deposits.

I have not been able to find an account of a limestone of exactly similar nature in Victoria. An outcrop of a tertiary limestone occurs six miles away at Green Gully, Keilor, but this is marine (4). A fresh-water limestone at Malmsbury is reported in the Catalogue of Rocks and Minerals (9), and is stated to contain much magnesium carbonate and to represent a product of the decomposition of basalt. A magnesian limestone of fresh water origin occurs at Coimaidai, near Bacchus Marsh (14), but differs from the Broadmeadows occurrence in the thin clay and chert bands which traverse the limestone. W. H. Ferguson (12) considers it as probably laid down in a lake occupying a hollow in the glacial conglomerate. R. A. F. Murray (13) judges it to be tertiary in age, and of fresh-water origin, or else a spring deposit. It is reported as hard in some places, soft in others, and in others highly brecciated and mixed with ferruginous clay. It has valuable hydraulic properties, and on comparing the analysis by J. C. Newbery it is seen to contain much less silica and clay than the Broadmeadows stone.

A tertiary fresh-water limestone also occurs in the valley of the Duck Ponds Creek. Analyses (15 and 9) show that it is very variable and only magnesian in part. It is noted on the quarter sheet as a limestone which makes good building lime, and may be made into cement when mixed with a proper proportion of clay. From a comparison with these rocks one may draw the conclusion that the Broadmeadows rock is too limited in extent and too impure to be ever of much economic importance.

Chemical Characters.

From the nature of the supposed origin of this limestone, and also from the fact that associated with weathered parts of the newer basalt we often find that magnesite has separated out in hard nodules, we might expect to find great variation in the magnesia percentage. Further, where the limestone has been deposited in the creek we might expect great variation in the amount of material insoluble in acids. Such we do find.

Specimen No. 39, collected from D, contains about one-third of insoluble material. Specimen No. 38, collected from C, is much more uniform in composition, and the insoluble material scarcely amounts to one-sixth. In the rock analysed by J. C. Newbery it is very much less, and only 5.94 per cent. The exact locality from which this specimen was taken is not marked on the quarter sheet, and therefore not precisely known.

The three analyses agree in a notable quantity of magnesia, and this fact led Professor Skeats to suggest that a thin section should be stained in order to determine whether any dolomite existed. Accordingly thin sections were prepared and subjected to Lemberg's test. A few drops of a solution of aluminium chloride and logwood are applied to the surface of the slice, and allowed to stand for a few minutes. The dolomite is unaffected, but over the calcite a gelatinous precipitate of aluminium hydrate is formed, and this is stained purple with the logwood. The section is then mounted in glycerine jelly. No decided differentiation resulted with the impure rock from D; but the rock from C gave very interesting results.

Petrographical Characters.

Specimen No. 38, collected from C, Section X., Will Will Rook. Megascopically this is a very hard, fine-grained, greyish and earthy limestone. It is slightly cavernous, and the caverns appear to be lined with more crystalline material. Scattered throughout are small crystals of quartz and occasional felspar and fragments of igneous material.

Microscopically the bulk of the rock is a crypto-crystalline mass of earthy carbonate in which are set angular and sub-angular crystals of quartz and occasional felspar. Isolated lumps of igneous material contain lumps of plagioclase felspar and grains of olivine set in a brownish glass, thus indicating basaltic material. Along the cracks and caverns in the slice crystallisation has occurred, and this has been well brought out by the staining. The crystallised material is for the most part purple, and therefore calcite in very minute crystals. But in many of the cavities, most pronounced in those completely filled with crystalline material, only the inner part consists of calcite, between which and the wall of the cavity is a ring of unstained dolomite, which is well defined from the ground-mass.

The rock may therefore be described as a dolomitic limestone.

Specimen No. 39, collected from D, is, megascopically, rather a loosely compacted, whitish rock, which contains numerous pebbles of rounded and sub-angular quartz, felspar and basaltic material, set in a white calcareous material. The pebbles are very loosely set, and readily torn out on slicing.

Microscopically, it is seen to consist very largely of quartz pebbles, lumps of basalt, and felspar set in an exceedingly fine-grained ground-mass of calcareous material. Re-crystallisation has not proceeded at all, and very little was gained by staining.

The rock may be described as a detrital limestone.

Alluvium.

The alluvium occurs in small quantity along the bed of the creeks. It is obviously derived partly from the granitic area, partly from the basalt, and partly from the silurian sediments. It is omitted from the accompanying map for the sake of clearness.

In conclusion, I should like to gratefully acknowledge the help of Professor E. W. Skeats and Mr. H. S. Summers, M.Sc., throughout the year 1910, when the work detailed in this paper was carried out. I am also indebted to Dr. Pritchard for information concerning shells from the limestone, to Mr. H. C. Richards, M.Sc., for the analysis of the granite, and to Mr. H. J. Grayson for the micro photographs. Mr. Grayson also gave valuable and greatly appreciated assistance in the preparation and staining of the rock slides.

Summary.

The Broadmeadows area includes a low granitic hill called Gellibrand's Hill, which gradually rises from a river valley to the south. The hill and valley are surrounded by a level basalt plain.

In the valley and central portion of the area a folded series of silurian sandstones, mudstones and shales outcrop. The granite is intrusive into this series. A chemical analysis by Mr H. C. Richards, M.Sc., and a petrographical examination prove that the granite is to be correlated with the devonian granodiorites of Victoria. In part the granite is kaolinised.

North-west of the Broadmeadows township occurs a volcanic series which rests, with only a thin intervening iron-stained clay bed, on both granite and silurian rocks. This series has been found chemically and petrographically related to the older basalt series of Victoria.

A tertiary quartzite and grit series is found underlying the newer basalt plain and outcrops along the valley walls. It is probably younger than the older basalt, but the relations are not clear.

The surrounding newer basalt forms the eastern fringe of the extensive volcanic plains of the Western District. It is petrographically described as an olivine anorthoclase (?) basalt.

In the valley and creek beds in the north-east portion of the area occurs a limestone. This limestone has an irregular distribution and shows great variability in character. It is imbedded and contains eroded boulders of newer basalt and shells of living organisms. It is therefore of recent age, and younger than the newer basalt, and has a chemical rather than a mechanical origin. Chemical analyses show that it is impure and highly magnesian, and a petrographical examination proves the presence of dolomite in small amount.

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Chemical Analyses.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	67.75	44.95	50.50	48.78	8.93	23.89	4.467	2.05
Al_2O_3	16.11	15.50	16.01	15.85	3.38	8.88		
Fe_2O_3	0.50	2.04	1.40	5.37	1.39	1.08	1.476	1.90
FeO	4.00	10.47	8.98	6.34				
MgO	0.79	7.43	6.13	6.03	12.75	12.85		
CaO	2.68	8.24	8.05	8.91	31.07	19.87		
Na_2O	2.60	3.04	3.08	3.18	1.81	2.68		
K_2O	3.42	1.98	2.02	1.63	0.63	0.71		
H_2O+	0.96	2.60	0.29	1.03	1.84	1.27		*
H_2O-	0.20	0.52	0.48	0.73				
CO_2	nil	0.18	0.68		38.04	27.94		
TiO_2	0.85	2.77	2.04	1.39				
P_2O_5	0.09	0.52	0.39	0.47				
MnO	trace	0.21	trace	0.29				
Total	99.95	100.45	99.97	100.00	99.84	99.17		
Sp. Gr.	2.68	2.91	2.86					
$CaCO_3$					54.91	33.34	54.974	55.00
$MgCO_3$					29.50	26.73	39.007	41.00
							99.924	100.00

* Water + loss = .05

I. Granite Quarry, Gellibrand Hill, Broadmeadows (analysed by H. C. Richards, M.Sc.).

II. Older basalt (A) Quarry, section xv., Tullamarine, County of Bourke.

III. Newer basalt (B), section vi., Will Will Rook, County of Bourke.

IV. Average of 161 analyses of typical basalts (largely olivine bearing), from various localities. R. H. Daly, Journ. of Geol., vol. xvi., 1908, p. 409.

V. Dolomitic limestone (C), section x., Will Will Rook, County of Bourke.

VI. Impure limestone (D), section xiv., Will Will Rook, County of Bourke.

VII. Impure limestone, section x., Will Will Rook, County of Bourke, analysed by J. C. Newbery. Descriptive Catalogue of Rocks and Minerals, National Museum (Selwyn), p. 57.

VIII. Limestone, Bacchus Marsh. Analysed by J. C. Newbery, Laboratory Report, 1890.

DESCRIPTION OF PLATES XLIII. AND XLIV.

Plate XLIII.

Map of Broadmeadows. Reproduced from the quarter-sheet No. 2, S.W., with slight modifications. Scale 2 inches to one mile.

Plate XLIV.

Fig. 1.—Olivine anorthoclase (?) basalt, older basalt series. The centre phenocryst is anorthite crowded with dark inclusions.

Fig. 2.—Olivine anorthoclase (?) basalt, newer basalt series. The olivine with its dark, altered border is in strong contrast to the clear olivine in fig. 1.